An Algorithmic Approach to Fixturing

B. MISHRA
New York University

ABSTRACT

With an increasing interest in manufacturing towards computer-assisted production in small batch sizes, researchers have begun to focus on the algorithmic approaches to fixturing, calibration, tool-path generation, etc. In this paper, we provide computational geometric algorithms to fixture $2\frac{1}{2}$-dimensional convex objects, thus extending our earlier works for $2\frac{1}{2}$-dimensional rectilinear objects.

While many of the key ideas are related to the theory of dextrous manipulation in robotics, the problems in fixturing differ in two fundamental ways, namely: (1) The accuracy and ambient force requirements are rather stringent (2) The available fixtures are geometrically more specialized than robot-hands.

1. Introduction

In manufacturing systems, fixturing devices are used to immobilize specific parts, while the final shape of the part is imparted by successive phases of cutting processes. In addition to immobilizing the structure, the fixturing devices (usually, clamps, jigs and fixtures) must be so placed that they do not interfere with the tool paths or the calibration process. Furthermore, the forces imparted by the jigs and fixtures must not exceed certain thresholds lest they may deform or destroy the stock. But, simultaneously they must guarantee that the parts being machined are immobilized to the extent that the results of the calibration and machining is within the tolerable accuracies.

Note, however, that unlike the usual mechanical structures, objects in manufacturing systems are required to withstand extremely high fluctuating cutting loads. For instance, it is quite common to require an accuracy of less than 0.025 mm and cutting loads as high as 20 KN. The problems relating to flexible fixturing has received a lot of attention in the recent years (see for instance, [1, 2].) However, most of the research in the area focuses on expert-system approaches, and thus, relies on existing heuristics, many of which are yet to be justified from an analytical viewpoint.

Some of the early algorithmic work in this area was done by the author (see Mishra[3]) and have been further extended by several computer scientists (particularly, the work at U.S.C. by Goldberg and his colleagues[4]). In this paper, we extend the earlier work to provide computational geometric algorithms to fixture $2\frac{1}{2}$-dimensional convex objects.

Here, we shall concentrate on the "small-batch milling," where the fixturing devices of choice are usually toe clamps and toggle clamps, which fit into the toe slots on the bed of the machine tool and then grab onto the part at convenient projections. These and other clamping devices can be used interchangeably, and in order to emphasize the implicit generality, we will refer to all of these clamps by the term "*fixels*" (i.e. *fix*turing *el*ements.)

2. Main Results

Fixels are usually constrained by certain severe geometric and kinematic conditions—for instance, the positions of toe clamps (and hence the contact points) that can be selected are constrained by the positions of the toe slots on the bed of the machine tool. Here we consider a simple arrangement of the toe slots: *They are arranged along the vertices of a unit grid on the bed of the machine tool.* The toe clamps fit into the toe slots and grab on to the part with a small projection.

In many cases, the part B to be machined can be assumed to be two-and-a-half dimensional, i.e. the object is cylindrical with a polygonal cross-section and of relatively small height. A toe clamp fixed to a toe slot, TS, will be able to make a contact on a vertical face within a unit distance of TS and at a point closest to TS. Note that while a toe slot TS can potentially contribute more than one contact point, in any clamping structure, at most one such contact point can be used.

Now the geometric constraints imposed by the toe slots and the kinematic constraints imposed by the toe clamps can be expressed as saying that all the fixels can only be at regular grid points and that unless a fixel is within a unit distance from the boundary of the part, it is ineffective.

The following theorems are for the case when the part is assumed to have *convex cross-section*

Theorem 2.1 *Let B be a $2\frac{1}{2}$-dimensional convex part whose cross-sectional polygon has edges all of length $2\sqrt{2}$ units or more. Then B can be clamped by at most 4 fixels (constrained as above).* $\square$

2.1 Cleanup

One important operation in manufacturing is to take a part that is approximately the desired finished product (within the tolerance) and to clean up each face. The cleanup operation takes a sequence of setups: each setup comprising of a clamping process, followed by a cutting process. Usually one tries to minimize the number of setups, while trying to keep the operations within each setup fairly simple (few clamps and few toolpaths).

Theorem 2.2 *Let B be a $2\frac{1}{2}$-dimensional convex part whose cross-sectional polygon has edges all of length $4\sqrt{2}$ units or more. Then B can be cleaned up in 2 setups—each setup uses at most 4 fixels (constrained as above).* $\square$

2.2 Part Creation

Lastly, we consider the operation of creating a part from a rectangular stock. As before, this operation requires a sequence of setups, and one tries to minimize the number of setups.

Theorem 2.3 *Let B be a $2\frac{1}{2}$-dimensional convex part whose cross-sectional polygon has edges all of length $2 + 4\sqrt{2}$ units or more. Then B can be constructed from a rectangular stock in 3 setups—each setup uses at most 8 fixels (constrained as above).* $\square$

The algorithms for constructing each setup in both the processes can be implemented in time linear in the number of faces of the parts.

References

[1] H. Asada and A. By. Kinematic Analysis of Workpart Fixturing for Flexible Assembly with Automatically Reconfigurable Fixtures. *IEEE Journal of Robotics and automation*, RA-1(2):86–94, December 1985.

[2] F. Brack Hazen and Paul Wright. Workholding Automation: Innovations in Analysis, Design and Planning. *Manufacturing Review*, 3(4):224–237, December 1990.

[3] B. Mishra. Workholding—Analysis and Planning. In *Proceedings: IEEE/RSJ International Workshop on Intelligent Robots and Systems: IROS'91*, pages 53–57, Osaka, Japan, November 1991.

[4] Y.-C. Wong and K. Goldberg. Algorithms for Configuring Modular Fixtures. Institute for Robotics and Intelligent Systems, U.S.C., L.A., April 1993.